Telerobotics for Human Exploration

Enhancing crew capabilities in deep space

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Exploration destinations
(one-way travel times)

- **International Space Station (2 days)**
- **Earth (3-7 days)**
- **Moon (3-7 days)**
- **Lagrange Points and other stable lunar orbits (8-10 days)**
- **Near-Earth Asteroid (3-12 months)**
- **Mars (6-9 months)**

Future missions will be longer, more complex, & require new technology

- Robotics and Mobility
- Deep Space Habitation
- Advanced Spacesuits
- Advanced Space Comm
- Advanced Propulsion
- Resource Utilization
- Human-Robot Systems
Telerobotics for Human Exploration

Part 1: Crew Surface Telerobotics

• Crew remotely operates surface robot from spacecraft
• Extends crew capability
• Enables new types of missions

Part 2: Interoperability

• Facilitate systems integration and testing
• Reduce development cost
• Expand international collaboration

Part 3: Common User Interfaces

• Common control modes
• Common interaction paradigms
• Enhance operator efficiency and reduce training time
Surface Telerobotics

**Concept of Operations**
- Crew remotely operates surface robot from spacecraft
- Proposed by numerous study teams for future missions
- Very little experimental data and validation to date

**Candidate Missions**
- **L2 Lunar Farside.** Orion MPCV at Earth-Moon L2 and rover on lunar farside surface
- **Near-Earth Asteroid.** NEA dynamics and distance prevent Earth-based manual control
- **Mars Orbit.** Crew operates surface robot when situation precludes Earth control

Credit: NASA GSFC
Studies

Surface Telerobotics (2012-14, NASA)

Avatar Explore (2009, CSA)

METERON (2014 ?, ESA)
Comparison

**Avatar Explore (CSA, 2009)**
- No Live Interaction
- High Latency (> 1h)
- Low Bandwidth
- Simple Task
- Target Location
- Real-time Teleoperation
- Low Latency (< 50ms)
- High Bandwidth
- High Degree of Freedom Manipulation

**Surface Telerobotics (NASA, 2012-14)**
- Interactive / Supervisory
- Moderate Latency (< 2s)
- Moderate Bandwidth
- Scouting, Survey
- Inspection, Servicing
- Structured Objects
- Force-Feedback Control
- Continuous Comms

**METERON (ESA, 2014 ?)**
- Natural Terrain
- Command-Based Control
- Intermittent Comms
- Planetary Rovers
- Controlled from Orbit
- Complex Tasks
NASA Surface Telerobotics

Goals

- Demo **crew-centric control** of surface telerobot from ISS (first operational system)
- Test **human-robot “opscon”** for future deep-space exploration mission
- Obtain **baseline engineering data** of system operation

Approach

- Leverage best practices and findings from **prior ground simulations**
- Collect data from robot software, crew user interfaces, and ops protocols
- Validate & **correlate to prior ground sim** (analog missions 2007-2011)

Implementation

- **Waypoint mission simulation**
- **K10 planetary rover** in ARC Roverscape (outdoor test site)
- **Astronaut on ISS** (10 hr total crew time, ISS Incr. 36)

Key Points

- **Complete human-robot mission sim**: site selection, ground survey, telescope deployment, inspection
- **Telescope proxy**: COTS 75 micron polyimide film roll (no antenna traces, no electronics, no receiver)
- **3.5 hr per crew session** (“just in time” training, system checkout, telerobot ops, & crew debrief)
- **Two control modes**: basic teleop and pre-planned command sequencing (with continuous monitoring)
- **Limited crew user interface**: no sequence planning, no science ops capability, no robot engineering data
Waypoint Mission

**Earth-Moon L2 Lagrange point**
- 60,000 km beyond lunar farside
- Allows station keeping with little fuel
- Crew remotely operates robot on Moon
- Cheaper than human surface mission
- Does not require human-rated lander

**Lunar telescope installation**
- Use telerobot to setup radio telescope on surface
- Requires surface survey, deployment, and inspection / documentation
- Lunar farside = radio quiet zone for low freq. measurements of cosmic dawn

Credit: Lockheed Martin

Credit: Univ. of Colorado / Boulder
Waypoint Mission Simulation (2013)

Phase 0
Pre-Mission Planning
Ground teams plan out telescope deployment and initial rover traverses.

Phase 1
Surveying / Scouting
Crew gathers information needed to finalize the telescope deployment plan.

Phase 2
Telescope Deployment
Crew monitors the rover as it deploys a single arm of a telescope node.

Phase 3
Telescope Inspection
Crew inspects the deployed telescope node looking for tears and folds.

Spring
Crew Session 1
June 17

June 17
Crew Session 2
July 10

July 10
Crew Session 3
August 8

Telerobotics for Human Exploration
Deployed Telescope Simulation

NASA Ames Roverscape
Robot Interface (Task Sequence Mode)

- Alert Bar
- Rover Status
- Tip Bar
- Tab Panel
- Bird's Eye 3D View
- Top Down 3D View
- Primary Button Panel
- Status Bar
- Terrain hazards
- Rover camera display

Task Sequence Controls

Telerobotics for Human Exploration
Robot Interface (Teleop Mode)

- Rover path
- Terrain hazards
- Rover camera display
- Motion controls
- Camera controls

Teleop Mode:
- Robot Interface
- Rover path
- Terrain hazards
- Rover camera display

Motion controls include:
- Forward
- Backward
- Rotate Left
- Rotate Right

Camera controls include:
- Panorama
- Inspection

Contents:
- Robot Interface Workbench
- Navigation tools
- Hazard detection
- Rover status
- Motion controls
- Camera controls

Nasa Telerobotics for Human Exploration
Experimental Protocol

Data Collection

Obtain engineering data through automatic and manual data collection

- **Data Communication**: direction (up/down), message type, total volume, etc.
- **Robot Telemetry**: position, orientation, power, health, instrument state, etc.
- **User Interfaces**: mode changes, data input, access to reference data, etc.
- **Robot Operations**: start, end, duration of planning, monitoring, and analysis
- **Crew Questionnaires**: workload, situation awareness, critical incidents

Metrics

Use performance metrics* to analyze data and assess human-robot ops

- **Human**: Bedford workload & SAGAT (situation awareness)
- **Robot**: MTBI, MTCI for productivity and reliability
- **System**: Productive Time, Team Workload, and task specific measures for effectiveness and efficiency of the Human-Robot system

*Performance metrics used for prior analog field tests: 2009 robotic recon, 2010 lunar surface systems, 2010 robotic follow-up, 2009-2011 Pavillion Lakes research project, etc.*
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Interoperability

Modern robots are highly complex systems
  • Many software modules (on-board and off-board)
  • Distributed development team
  • Standardized framework facilitates interoperability

Benefits of interoperability
  • Facilitate integration and testing
  • Reduce cost and risk
  • Enhance operational flexibility and capabilities

Robots that do not speak the same “language” are a major obstacle to collaboration in space exploration …
CCSDS Telerobotics Standard

MOIMS-TEL

- Mission Operation & Info. Management Area
- Telerobotics Working Group
- Develop interoperability standards applicable to multiple projects and missions

Focus

- Compatibility “layer” that facilitates command and data exchange
- Specification for software data structures
  - Message formats
  - Application Programming Interfaces (API)
  - Functional description of standard services

This is NOT …

- All-encompassing system for robot data comm
- Set of standards governing space robotics

Chairs: David Mittman (JPL)
Lindolfo Martinez (JSC)
Interoperability Standard Development

Approach
- Adopt best practices and lessons learned from relevant work
- Develop recommendations based on future mission needs
- Consider existing CCSDS standards (where appropriate)

Relevant work
- CCSDS Asynchronous Message Service (AMS)
- CCSDS Application Support Services (APP)
- CCSDS Mission Operations (MO)
- IETF Delay-Tolerant Networking (DTN)
- OMG Common Object Request Broker Architecture (CORBA)
- OMG Data-Distribution Service for Real-Time Systems (DDS)
- NASA Robot Application Programming Interface Delegate (RAPID)
- SAE Joint Architecture for Unmanned Systems (JAUS)
- etc.
Robot Application Programming Interface Delegate (RAPID)

- Provides Message Definitions & API
- Provides Common Services API
- Developed by ARC, JPL, and JSC with assistance from GRC, LaRC, and KSC

Implementation

- Uses Data-Distribution Service
  - International standard (OMG)
  - Publish-subscribe communications
- RTI DDS provides data transport (middleware) layer
- Open-source release (Apache 2)
RAPID Robots

K10 planetary rovers

Smart SPHERES

Centaur 2 robot

Lunar Surface Manipulator System

Space Exploration Vehicle

Tri-ATHLETE

X-Arm-2
RAPID User Interfaces
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Robot User Interfaces

**Space robots**
- Space robots have very diverse forms (size, shape, movement, etc)
- Many different control modes (manual to safeguarded to supervisory)
- Broad range of tasks (mobility, field work, positioning, etc.)

**User interfaces**
- Robots have custom user interfaces and custom interaction modes
- Users need to relearn control methods for each new robot
- Very difficult to port new control modes from robot to robot

Multiple, complex and/or inconsistent robot user interfaces result in increased training, reduced operational efficiency and higher crew workload
Robot User Interfaces
Operator Interface Standards

**Industrial Robots**

- ANSI/RIA R15.06-1999
  - Guidelines for industrial robot manufacture, installation, and safeguarding for personnel safety
- ANSI/RIA R15.02-1-1990
  - Guidelines for the design of operator control pendants for robot systems

**Ergonomics**

- NASA Man-Systems Integration Standards
  - Human-systems integration design considerations & requirements
- MIL-STD-1472F
  - General human engineering criteria for military systems
Common User Interfaces

**Standardized Interactions**

- Common set of commands that will produce *predictable* and *consistent* robot behaviors
- Common *interaction paradigms* (for different control modes)
- Common *information displays* (standard semantics)

**Benefits**

- Help users avoid inadvertently sending erroneous commands when switching between different types of robots
- Enhance operator efficiency
- Reduce training time (initial & proficiency maintenance)
Common Ground Vehicle Interfaces

Honda Civic

Pontoon boat

Forklift

Riding lawnmower

School bus
Common User Interfaces

How will crew operate

• Surface robots from orbit?
• Side-by-side with robots?
• Many types of robots for different tasks?

Deep Space

Asteroids & Near-Earth Objects

Mars, Phobos, & Deimos

Lunar Orbit, Lunar Surface (Global)

International Space Station

Low-Earth Orbit
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